A Quick Start for Working with SIDM Halos

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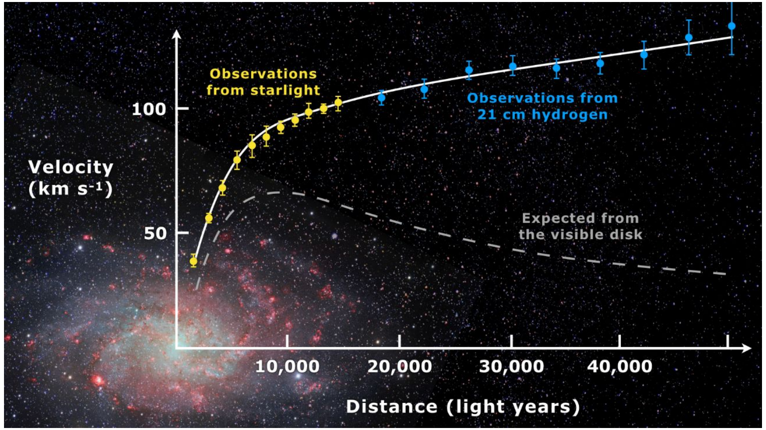
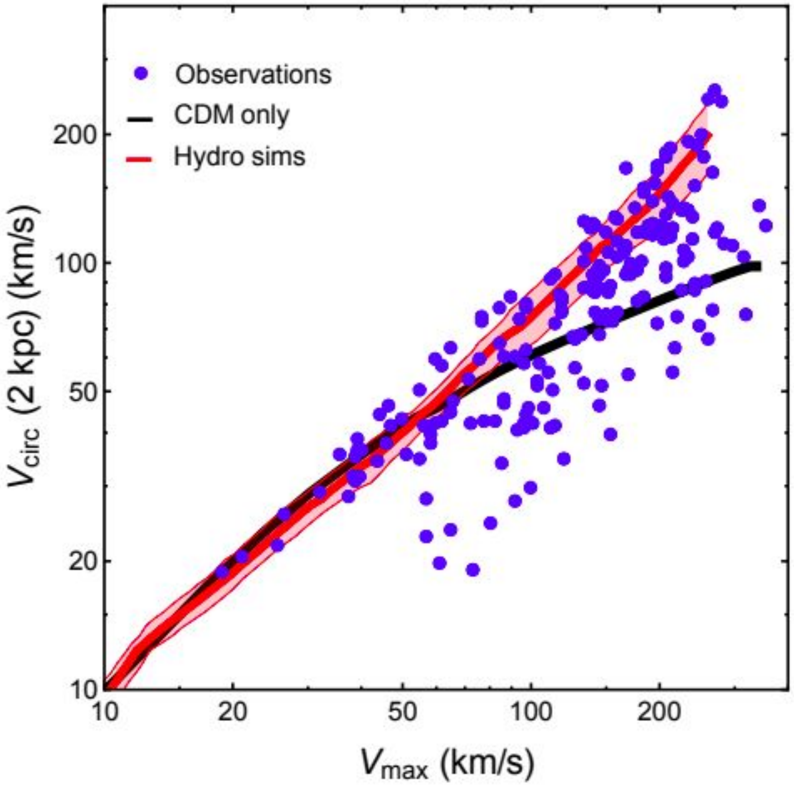
Puzzles in small scale observations

Tulin and Yu 2017 (Review)
data compiled in Oman+ 2015

- **The diversity problem ->**
- Core vs Cusp
- Too Big To Fail
- Ultra-diffuse galaxies
- DM-deficient galaxies
- Dense lensing perturber
- … …





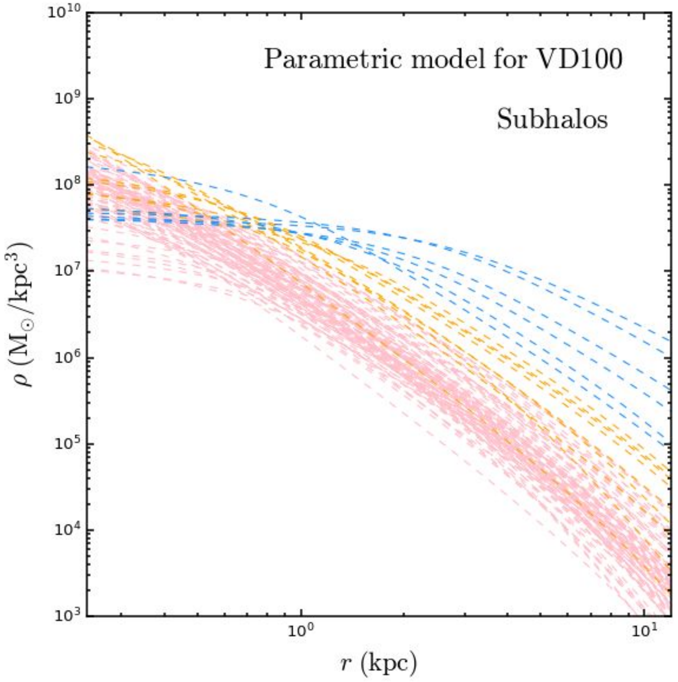
SIDM helps!
Dark matter can have elastic scatterings at small scales

- Elastic scatterings conserve energy and momentum
- Scattering cross section can have angular and velocity dependencies
- Particle dynamics couples to halo structure:

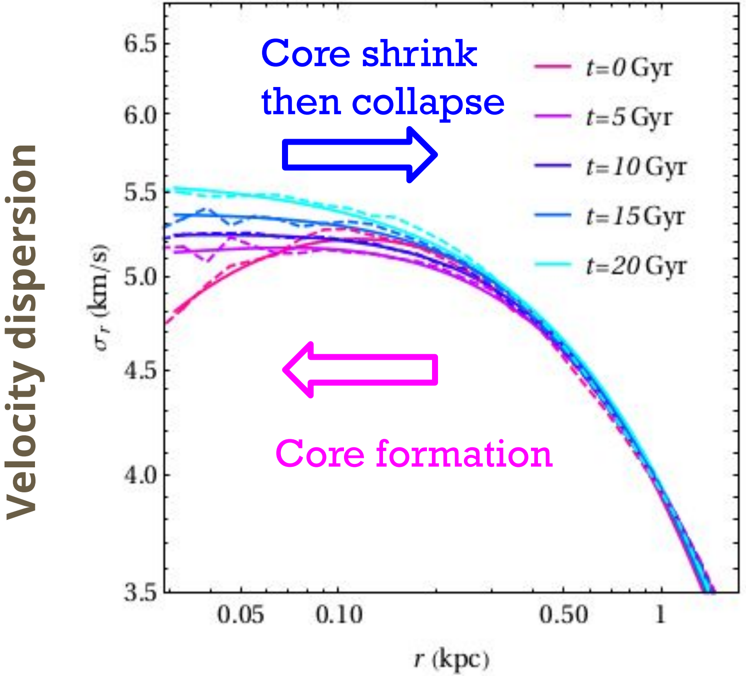
  enriching small scale structures

SIDM enriches inner halo structures

T=m v^2



For > 100 Milky Way subhalos
A strong and velocity dependent cross section



SIDM leads to a self-gravitating & thermalizing system

Gravothermal evolution

Core formation

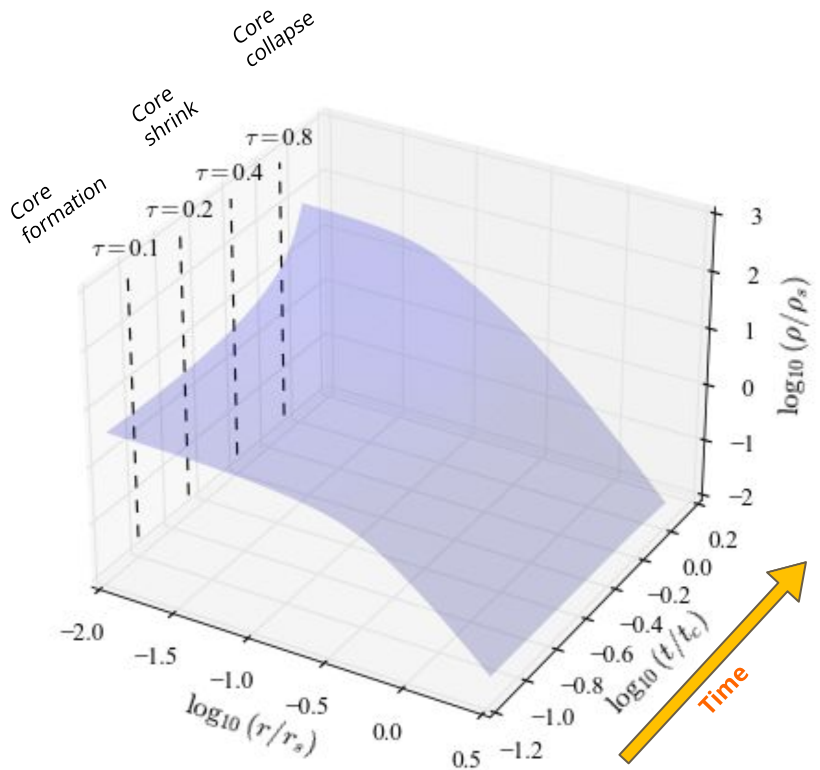
- energy flux + capacity => core formation

Core shrink

+ energy flux + capacity => quasi-stable core

Second stage

+ energy flux - **capacity** => **core collapse**

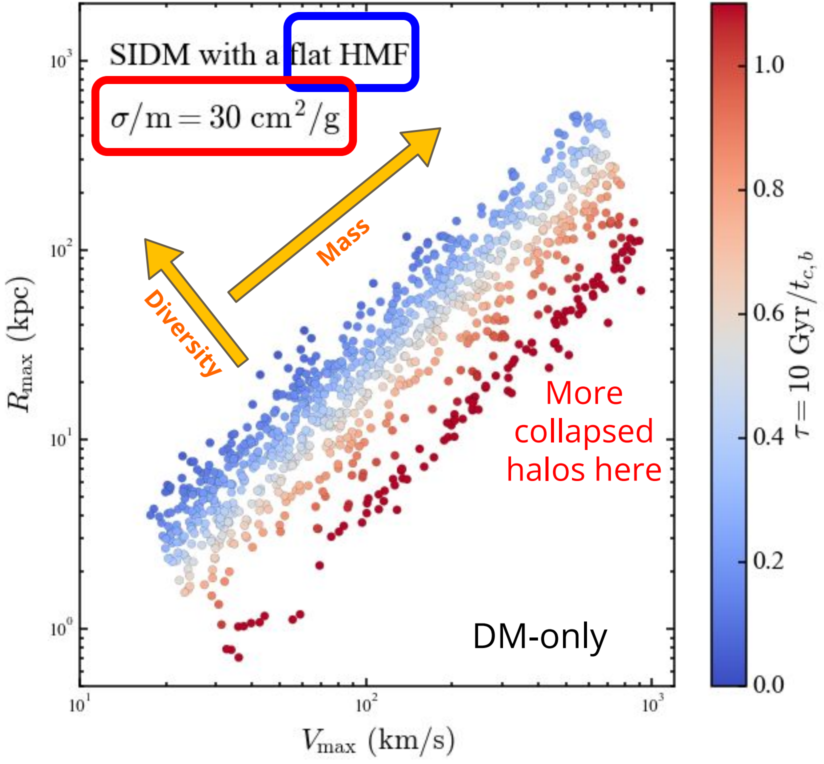


Thermodynamic quantities reconstructed from N-body simulations (JCAP 09 (2022) 077)

A constant SIDM cross section does not affect halos in the same way

Collisional relaxation

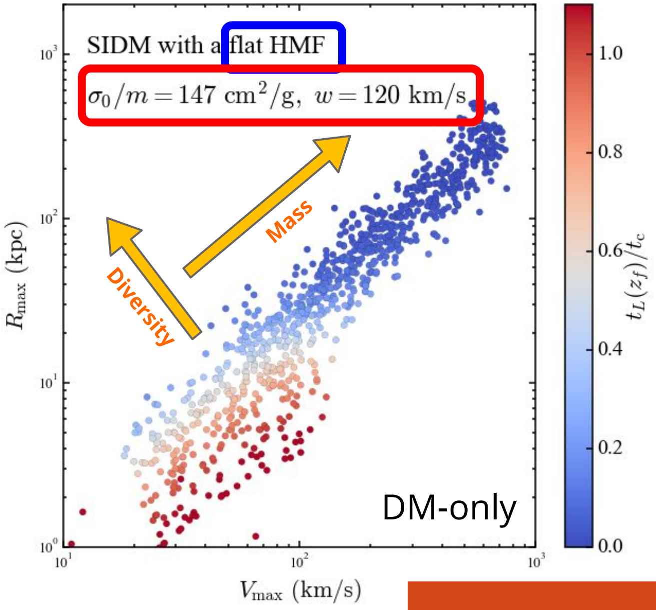
$$t_{c,0} = \frac{150}{C}\frac{1}{\frac{\sigma}{m}\rho_s}\left(\frac{1}{4\pi G\rho_s r_s^2}\right)^{\frac{1}{2}}$$

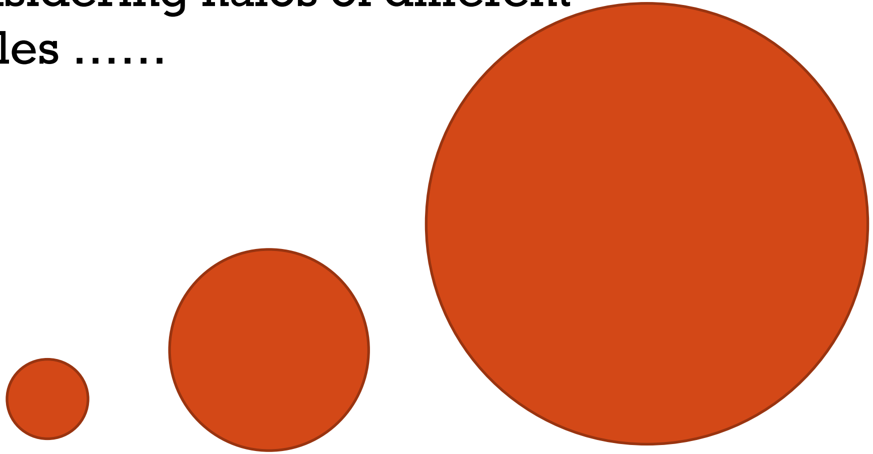


Phys. Rev. Lett. 123, 121102 (2019)
Astrophys. J. 568, 475–487 (2002)

Opportunities

- Rich existing & upcoming observations
- Particle physics scattering information can be recovered by considering halos of different scales ……





	Halo 1	Halo 2	Halo 3
Model 0	SIDM 1	SIDM 1	SIDM 1
Model 1	SIDM 10	SIDM 1	SIDM 0.1
Model 2	SIDM 100	SIDM 10	SIDM 0.01

A "clock" in the gravothermal evolution

SIDM generates an arrow of time

Normalized to give a "clock" / "phase"

$$\frac{\partial}{\partial r}\left(r^2 \kappa m \frac{\partial \nu^2}{\partial r}\right) = r^2 \rho \nu^2 \frac{D}{\boxed{Dt}} \ln \frac{\nu^3}{\rho}$$

When **κ** ∝ # of scatterings ∝ **σ** (long-mean-free-path regime)

The **cross section (σ)** dependence can be absorbed into the **arrow of time: t -> t σ**

$$\tilde{t} \equiv t/t_c$$

The parametric model

A simple yet accurate method to obtain SIDM predictions

- Based a few analytic formulae: efficient
- Grounded in theory principles
- Tested against a large number of halos in cosmological simulations
- Has been extended to incorporate mass changes and baryon potentials

https://github.com/DanengYang/parametricSIDM

Hands on

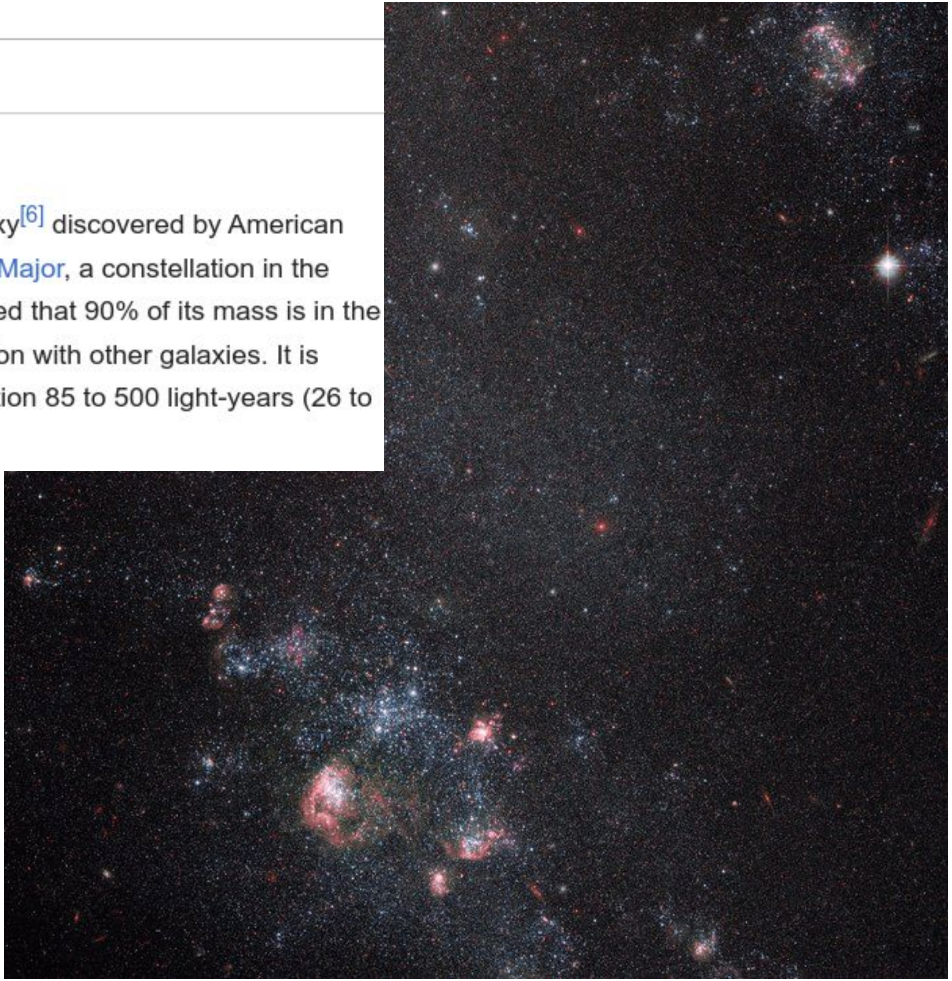
https://github.com/DanengYang/parametricSIDM/tutorial

IC 2574

Article Talk

From Wikipedia, the free encyclopedia

IC 2574, also known as Coddington's Nebula, is a dwarf spiral galaxy[6] discovered by American astronomer Edwin Foster Coddington in 1898.[8][9] Located in Ursa Major, a constellation in the northern sky, it is an outlying member of the M81 Group. It is believed that 90% of its mass is in the form of dark matter.[10] IC 2574 does not show evidence of interaction with other galaxies. It is currently forming stars; a UV analysis showed clumps of star formation 85 to 500 light-years (26 to 150 pc) in size.[11]



Model the baryon distribution using Hernquist / exponential disk profiles

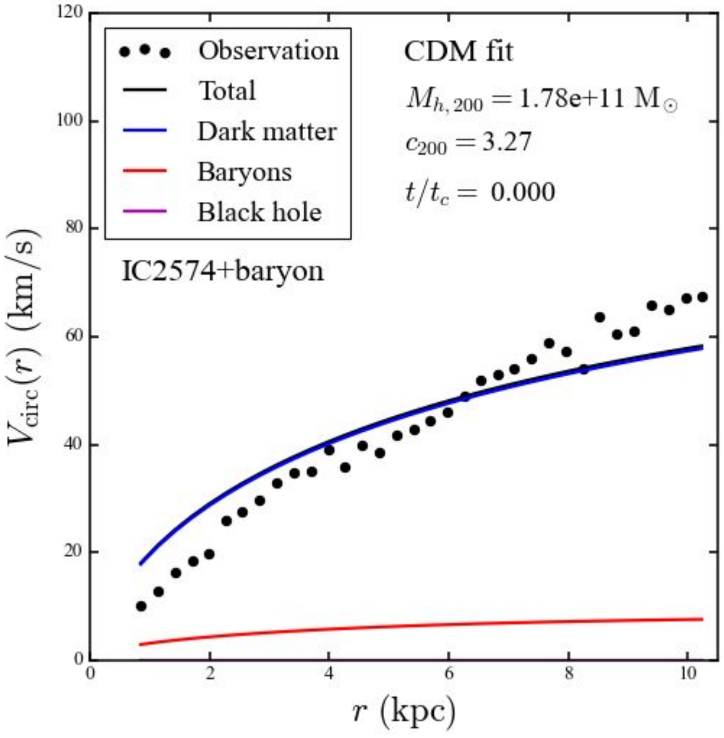
Re=3.18

Mb=5.08e8 Msun

rH=1.317 kpc

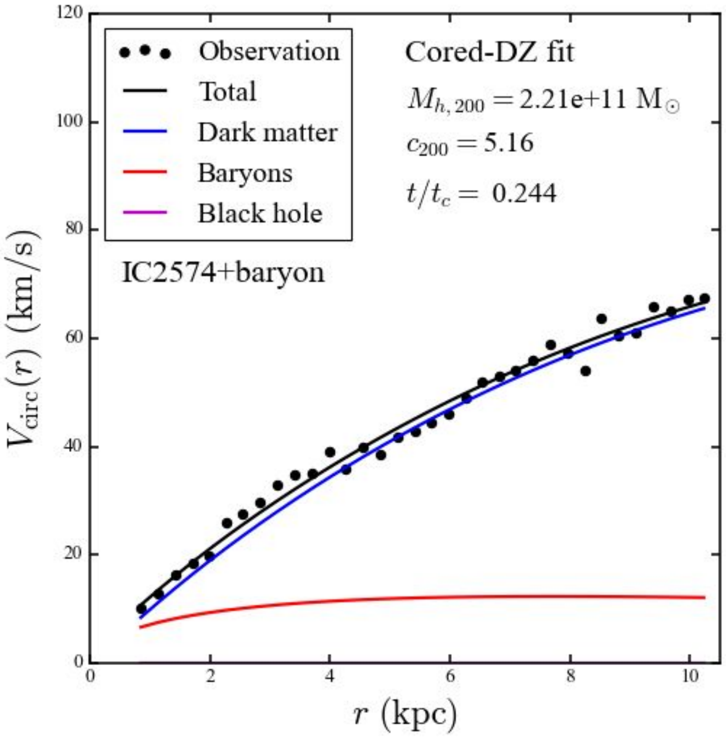
rhoH= 3.5378e7 Msun/kpc^3

CDM



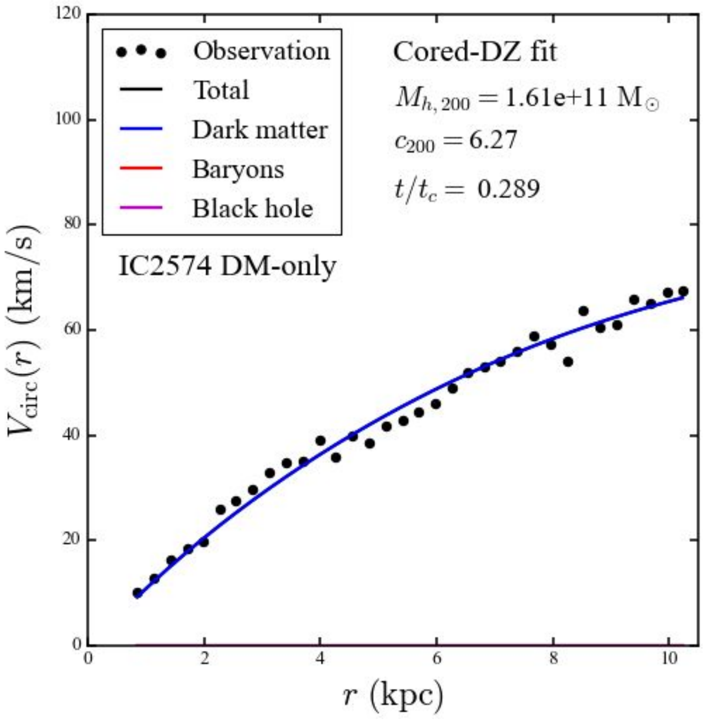
Observation
Total
Dark matter
Baryons
Black hole
CDM fit
$M_{h,200} = 1.78\text{e+}11\ \mathrm{M}_\odot$
$c_{200} = 3.27$
$t/t_c = 0.000$
IC2574+baryon
$V_{\mathrm{circ}}(r)$ (km/s)
r (kpc)

SIDM

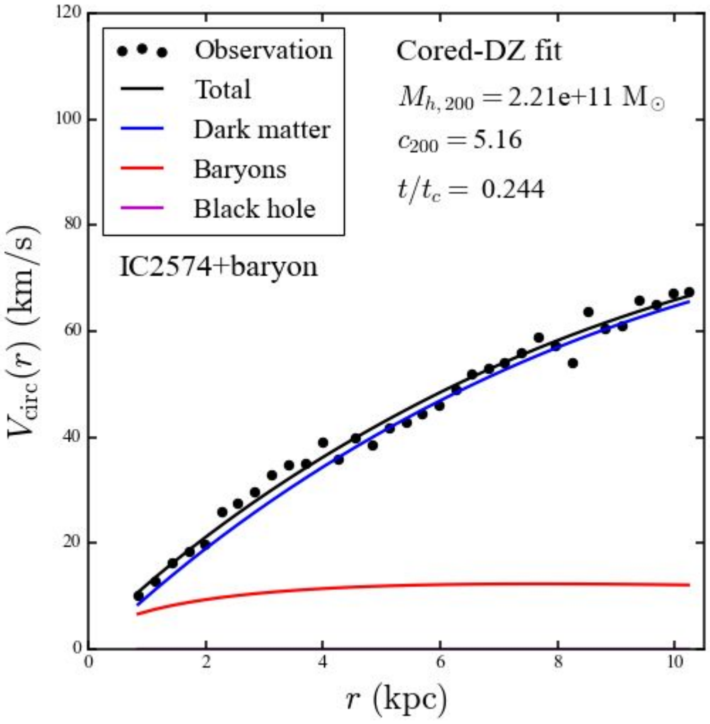


Observation
Total
Dark matter
Baryons
Black hole
Cored-DZ fit
$M_{h,200} = 2.21\text{e+}11\ \mathrm{M}_\odot$
$c_{200} = 5.16$
$t/t_c = 0.244$
IC2574+baryon
$V_{\mathrm{circ}}(r)$ (km/s)
r (kpc)

DM-only



DM+baryons



Messier 81

Ms=6.38e10 Msun

Diameter=28.4 kpc

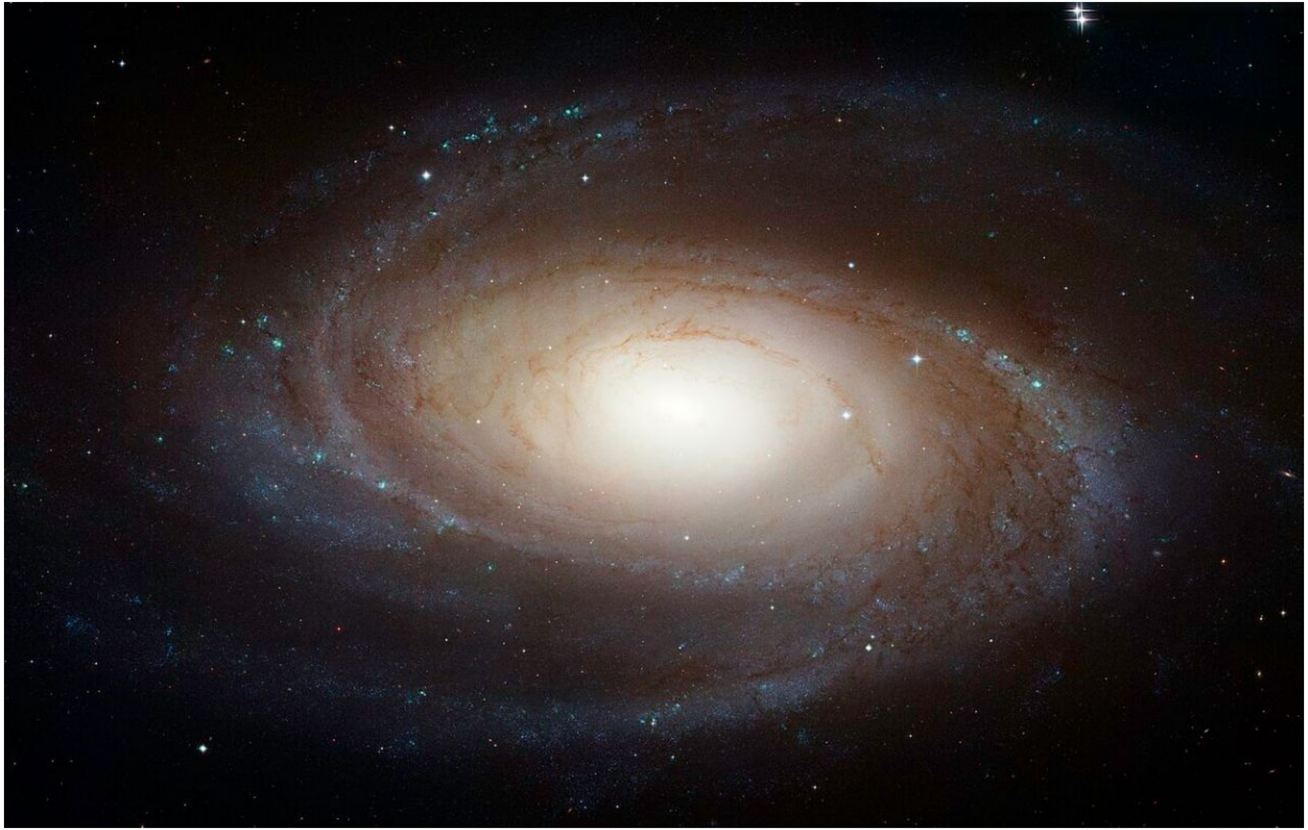
Re~28.4/2/2~7 kpc

Hernquist params
rH=(sqrt(2)-1)*4/3*Re=
3.92 kpc

rhoH=Ms/(2*pi*rH^3)
=1.686e8

(Exponential disk used in the fit)

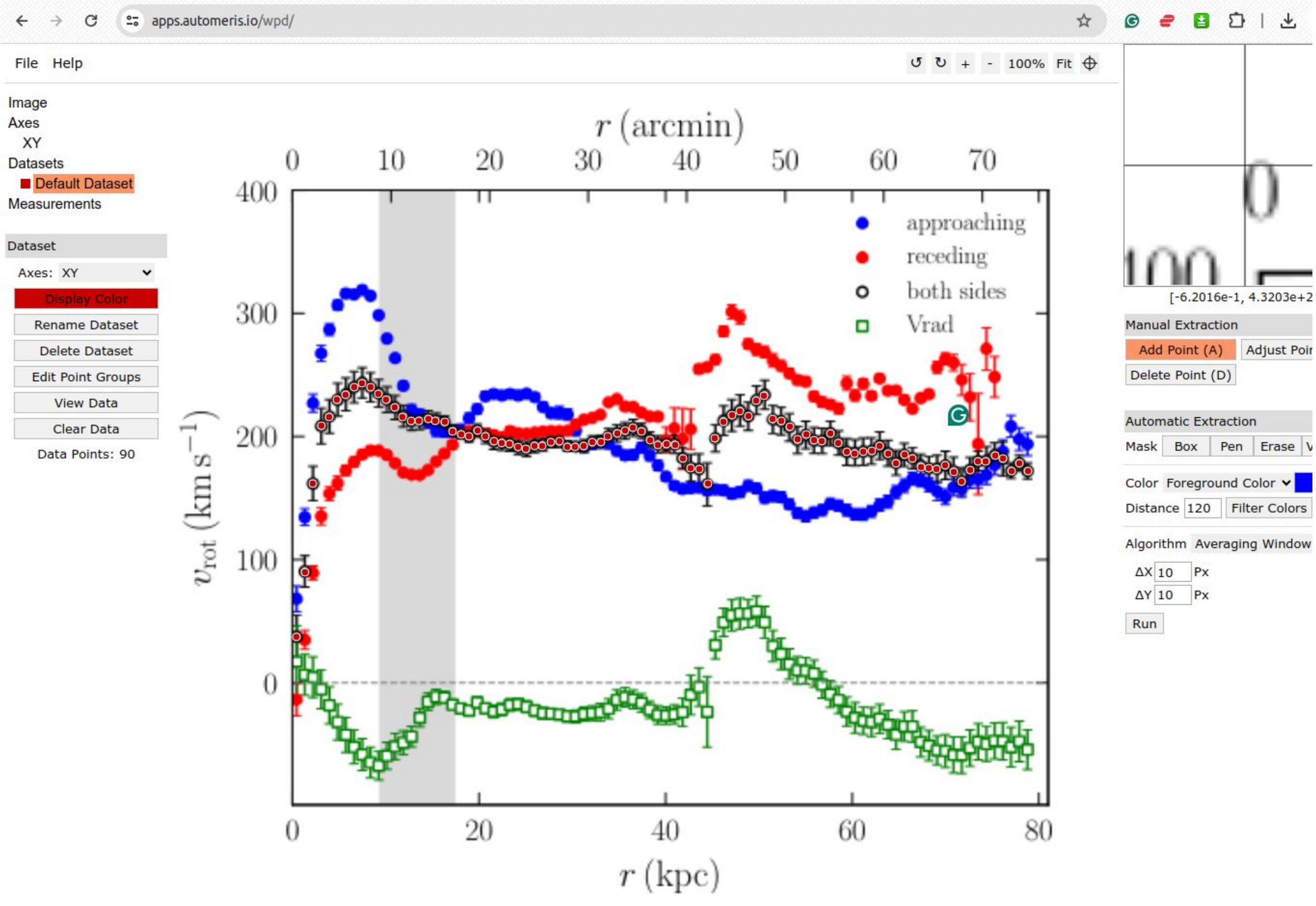
*MBH=7e7 Msun



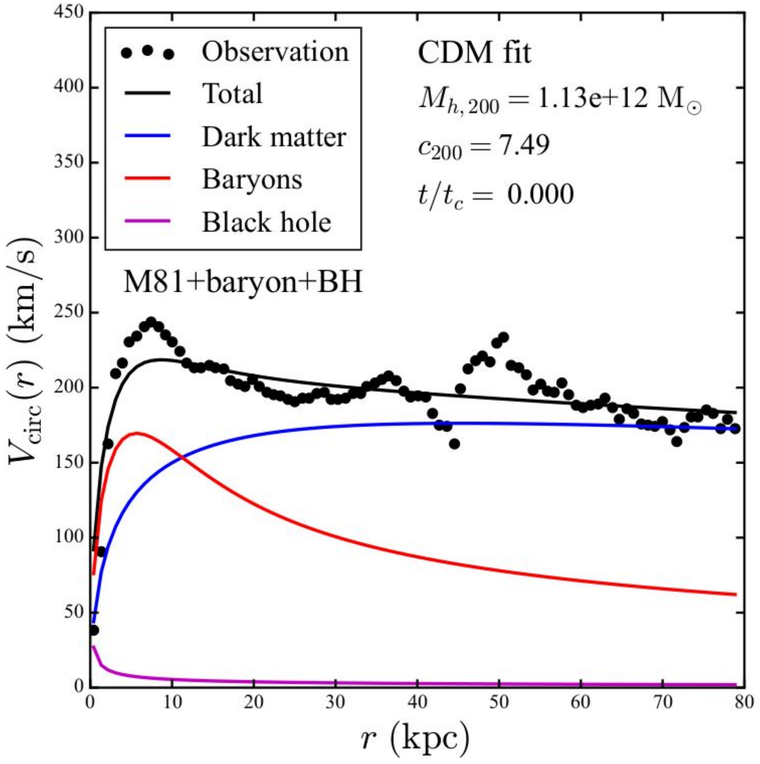
Extracting the Rotation curve

Webplotdigitizer

https://automeris.io/WebPlotDigitizer.html



CDM



Observation
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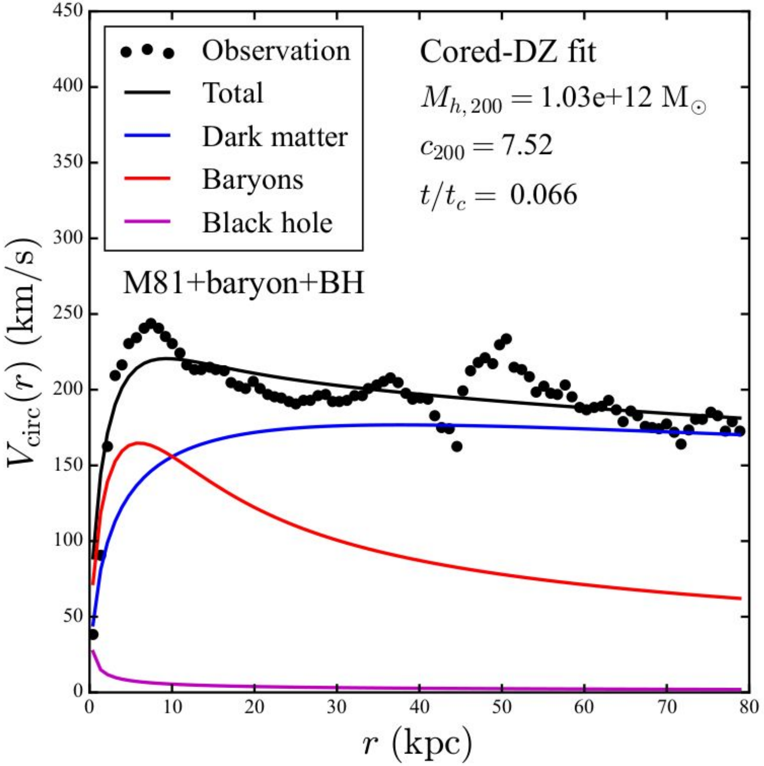
CDM fit
$M_{h,200} = 1.13\text{e+}12\ M_\odot$
$c_{200} = 7.49$
$t/t_c = 0.000$
M81+baryon+BH
$V_{\rm circ}(r)$ (km/s)
r (kpc)

SIDM



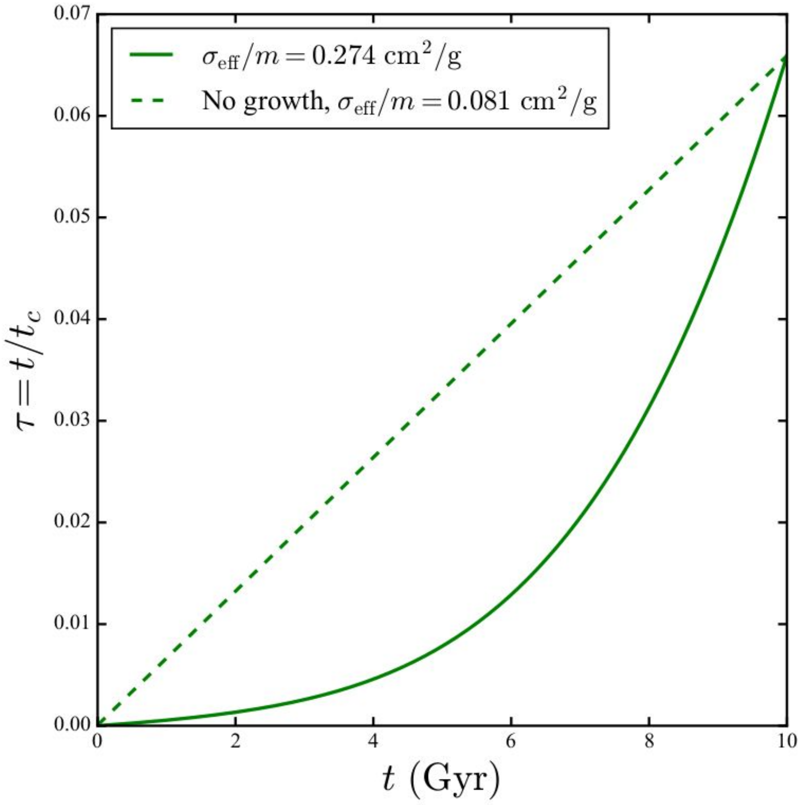
Observation
Total
Dark matter
Baryons
Black hole
Cored-DZ fit
$M_{h,200} = 1.03\text{e+}12\ M_\odot$
$c_{200} = 7.52$
$t/t_c = 0.066$
M81+baryon+BH
$V_{\rm circ}(r)$ (km/s)
r (kpc)

Effect of baryon growth

Each gravothermal state ( ) can arise from a “***fictitious***” progenitor of the same CDM halo & configurations.

$$\rho_{\mathrm{SIDM}}(r, \text{“CDM” halo \& baryon params at } t, \tau)$$
$$\Downarrow \quad t \to t + \delta t$$
$$\rho_{\mathrm{SIDM}}(r, \text{“CDM” halo \& baryon params at } t + \delta t, \tau + \delta\tau)$$

Effect of evolution history is obtained through an integral approach



Integral approach

Subhalo

$$V_{\max}(t) = V_{\max,\mathrm{CDM}}(t) + \int_0^{\tau(t)} d\tau' \frac{dV_{\max,\mathrm{Model}}(\tau')}{d\tau'}$$

$$\tau(t) = \int_0^t \frac{dt}{t_{c,b}[\sigma_{\mathrm{eff}}(t)/m, \rho_s(t), r_s(t), \rho_H(t), r_H(t)]}$$

Consistently compute δτ incorporating the accretion in CDM & effective SIDM cross section

Check our papers for details
arXiv:2305.16176
arXiv:2405.03787